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Effects of Dietary Protein and Feeding Rate on Channel Catfish *Ictalurus punctatus* Production, Composition of Gain, Processing Yield, and Water Quality

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Abstract

A 2 × 4 factorial experiment was conducted to examine effects of dietary protein level (28, 32, 36, and 40%) and feeding rate (satiation or ≤ 90 kg/ha per d) on production characteristics, processing yield, body composition, and water quality for pond-raised channel catfish *Ictalurus punctatus*. Fingerling channel catfish with a mean weight of 64 g/fish were stocked into 40 0.04-ha ponds at a rate of 17,290 fish/ha. Fish were fed once daily to apparent satiation or at a rate of ≤ 90 kg/ha per d for 134 d during the growing season. Dietary protein concentration had no effect on feed consumption, weight gain, feed conversion, survival, aeration time, or on fillet moisture, protein, and fat levels. Fish fed to satiation consumed more feed, gained more weight, had a higher feed conversion, and required more aeration time than fish fed a restricted ration. Visceral fat decreased, and fillet yield increased as dietary protein concentration increased to 36%. Carcass yield was lower for fish fed a diet containing 28% protein. Increasing feeding rate increased visceral fat but had no major effect on carcass, fillet, and nugget yields. Fish fed to satiation contained less moisture and more fat in the fillets that those fed a restricted ration. Nitrogenous waste compounds were generally higher where the fish were fed the higher protein diets. Although there was a significant interaction in pond water chemical oxygen demand between dietary protein and feeding rate, generally ponds in the satiation feeding group had higher chemical oxygen demand than ponds in the restricted feeding group. There was a trend that pond water total phosphorus levels were slightly elevated in the satiation feeding group compared to the restricted feeding group. However, pond water soluble reactive phosphorus and chlorophyll-a were not affected by either diet or feeding rate. Results from the present study indicate that a 28% protein diet provides the same level of channel catfish production as a 40% protein diet even when diet is restricted to 90 kg/ha per d. Although there was an increase in nitrogenous wastes in ponds where fish were fed high protein diets, there was little effect on fish production. The long term effects of using high protein diets on water quality are still unclear. Feeding to less than satiety may be beneficial in improving feed efficiency and water quality.

Pond-raised channel catfish *Ictalurus punctatus* are typically fed feeds containing 28 or 32% protein although they grow equally well when fed feeds containing lower levels of protein (Brown and Robinson 1989; Li and Lovell 1992a; Robinson and Li 1999a, 1999b). It has generally been assumed that for low protein diets to be effective, channel catfish should be fed to satiety—a practice that may decrease feed efficiency, increase fattiness, and contribute excess nutrients and undigested feed waste to the pond environment (Robinson and Li 1997; Boyd and Tucker 1998). Feeding to satiety is difficult to achieve because it is a highly subjective practice that invariably results in uneaten feeds, which negatively affects feed conversion and water quality. Also, feeding to satiety generally results in excess energy intake that often leads to increased fattiness, particularly if the digestible energy to protein (DE:P) ratio of the diet is higher than acceptable. Unassimilated feed could increase organic waste in the pond and increase biochemical oxygen demand of

TABLE 1. *Ingredient composition of experimental diets (percentage, as-fed).*

	Dietary protein (%)			
Ingredient	28	32	36	40
Soybean meal (48%[a])	35.6	44.5	53.4	62.4
Cottonseed meal (41%)	5.0	7.5	10.0	12.5
Poultry by-product meal (65%)	4.0	4.0	4.0	4.0
Com grain	33.0	26.7	20.5	14.1
Wheat middlings	20.0	15.0	10.0	5.0
Dicalcium phosphate	0.7	0.57	0.44	0.31
C-free vitamin mix[b]	0.07	0.07	0.07	0.07
Vitamin C[c]	0.03	0.03	0.03	0.03
Trace mineral mix[b]	0.1	0.1	0.1	0.1
Catfish offal oil[d]	1.5	1.5	1.5	1.5
DE:P ratio[e] (kcal/g)	10.26	9.16	8.31	7.62
Dietary protein by analysis[f] (% on a 90% dry matter basis)	28.5 ± 1.6	32.7 ± 1.6	37.0 ± 1.4	38.8 ± 2.4

[a]*Numbers in parentheses represent percentage crude protein.*
[b]*Same as described by Robinson and Li (1996).*
[c]*Provided by L ascorbyl-2-polyphosphate (25% activity).*
[d]*Sprayed on finished feed.*
[e]*DE:P ratio = digestible energy to crude protein ratio. DE was estimated based on tabular values of NRC (1993) and Robinson and Li (1996).*
[f]*Values represent the mean ± SD crude protein concentrations of feed samples collected.*

aquaculture systems (Johnson et al. 1993; Kelly and Karpinski 1994). Tucker et al. (1979) and Cole and Boyd (1986) reported that as feeding rate increased, ammonia, nitrite, carbon dioxide, chemical oxygen demand (COD), chlorophyll-*a*, and time of aeration increased in channel catfish ponds, whereas dissolved oxygen concentrations decreased.

There is evidence that feeding channel catfish feeds high in protein reduces fattiness, increases processing yield, and improves feed conversion (Robinson and Li 1997; Li et al. 2000). This strategy could also minimize feed input, reducing organic waste accumulation in ponds; thus, improving water quality. On the other hand, high protein diets could increase nitrogenous wastes (Li and Lovell 1992b) unless care is taken to ensure that feeding rate is restricted (Tucker et al. 1979; Cole and Boyd 1986). The present study was conducted to evaluate the effects of feeding high protein diets at levels less than satiety on production, processing yield, body composition, and water quality for channel catfish raised in earthen ponds from fingerlings to a marketable size.

Materials and Methods

Four practical feeds (Table 1) containing 28, 32, 36, or 40% crude protein with digestible energy to protein (DE:P) ratios of 10.3, 9.2, 8.3, and 7.6 kcal/g protein, respectively, were formulated based on digestible nutrients and energy to meet or exceed all known nutritional requirements of channel catfish (NRC 1993). The DE value of each diet was estimated based on tabular values of NRC (1993) and Robinson and Li (1996). The experimental feeds were not formulated to be isocaloric because in commercial feed formulations there is no practical way to adjust digestible energy and maintain dietary fat and fiber levels in the desirable ranges. The feeds were manufactured as extruded floating pellets in an experimental feed mill at the Delta Western Research Center (DWRC), Indianola, Mississippi, USA. Fresh lots of each feed were manufactured monthly. All dietary ingredients were obtained from the DWRC and were from commercial sources. Dietary protein levels were verified by the combustion method (AOAC 2000) using FP-2000 protein determinator (Leco Corporation, St. Joseph, Michigan, USA).

Channel catfish fingerlings (mean weight 63.8 g) were stocked into 40 0.04-ha earthen ponds at a density of 17,290 fish/ha. Five ponds were used for each dietary protein concentration × feeding rate combination. Fish were fed once daily to either apparent satiation or at a restricted ration for 134 d during the growing season. Initially, all fish were fed as much as they could eat within 20 min, post-feeding until feed consumption reached a predetermined level or "cutoff" point of 90 kg/ha per d. Thereafter, the daily feeding rate for fish in the restricted feeding group remained ≤ 90 kg/ha per d. Fish in the satiation feeding group were fed as much as they would eat for the entire growing season. Daily amount of feed fed was recorded for all ponds to determine mean feed consumption per fish at the end of the study.

During the growing season, water temperature and dissolved oxygen were monitored in early morning, mid-afternoon, and throughout the night using a YSI model 58 polarographic oxygen meter (Yellow Springs Instrument Company, Yellow Springs, Ohio, USA). Emergency aeration was provided by a 0.5-hp electrical aerator (Model AF-55, Air-O-Lator Corporation, Kansas City, Missouri, USA) and used in each pond once dissolved oxygen levels decreased to 4 mg/L. Total ammonia-nitrogen (TAN), nitrite-nitrogen (NO_2-N), and pH were measured weekly for the duration of the study at approximately 1300 to 1600 h using a field kit (Hach Chemical Co., Loveland, Colorado, USA). Un-ionized ammonia-nitrogen (NH_3-N) was calculated based on TAN concentrations and maximum water temperature and pH (Emerson et al. 1975; Tucker and Robinson 1990). Total phosphorus (TP) (acid persulfate digestion), soluble reactive phosphorus (SRP) (ascorbic acid method), total nitrogen (TN) (alkaline persulfate oxidation/digestion followed by chromotropic acid reaction), and COD (reactor digestion) were determined spectrophotometrically using methods outlined by Hach Company (1999). Chlorophyll-a was determined spectrophotometrically using ESS method 150.1 of Wisconsin State Lab of Hygiene (1991). Pond water chloride concentration was maintained at 50 mg/L or above by addition of salt (NaCl) to alleviate possible nitrite toxicity to the fish. Dead fish were removed from ponds, weighed, and recorded for correction of feed conversion ratio at the end of the study.

Upon termination of the study, all fish were harvested, counted, and weighed. Thirty marketable-size fish ranging 570–900 g/fish were removed from each pond and stunned by a 40-V electric pulse (Sylvesters, Inc., Louisville, Mississippi, USA). These fish were weighed collectively by pond, headed mechanically (Baader, Lübeck, Germany), eviscerated, and visceral fat removed and weighed. The headed and gutted carcasses were weighed, and then filleted and skinned by a fillet machine (Baader). Fillets were trimmed by hand and weighed. Visceral fat content and yields of headed and gutted carcasses, shank fillets, and nuggets were determined as percentages of whole body weight. Fillets (one fillet per fish, ten fish per pond) were stored at 20 C for subsequent proximate analyses.

Individual fillet samples were separately ground into a paste using a food processor. A portion of the ground fillet was lyophilized using Freezone Freeze Dry System (Labconco, Kansas City, Missouri, USA) for 16 to 18 h for subsequent protein and fat analyses. Proximate analyses were conducted in duplicate on individual fillet samples using methods described by AOAC (2000). Crude protein of fillet samples was determined by combustion using a FP-2000 protein determinator (Leco Corporation), crude fat by ether extraction using Soxtec System (Foss North America, Inc., Eden Prairie, Minnesota, USA), moisture by oven drying using a mechanical convection oven (Precision, Winchester, Virginia, USA), and ash by using a muffle furnace (Type 30400, Barnstead Thermolyne Corporation, Dubuque, Iowa, USA).

Data on production characteristics, processing yield, and fillet composition were subjected to ANOVA with subsequent separation of means via the Fisher's protected LSD procedure (Steel et al. 1997) using Statistical Analysis System (SAS) version 8.0 software (SAS Institute, Inc., Cary, North Carolina, USA). Water quality data were analyzed as repeated measurements using the MIXED procedure with heterogeneous compound symmetry of SAS. Ponds were used as the experimental units with variation among ponds within treatments used as the experimental error in tests of significance. A significance level of $P \leq 0.05$ was used.

TABLE 2. *Means of production characteristics of pond-raised channel catfish fed once daily to satiation or at a rate of ≤ 90 kg/ha per d with feeds containing various levels of protein.*

Dietary protein (%)	Feeding rate[a]	Feed consumption (g/fish)	Weight gain[b] (g/fish)	Feed conversion (feed/gain)	Survival (%)	Aeration time (hours)
Individual treatment means[c]						
28	R	610	459	1.33	95.2	801
28	S	811	525	1.55	98.3	966
32	R	635	458	1.39	97.9	756
32	S	828	512	1.62	97.4	897
36	R	640	455	1.42	96.6	813
36	S	807	534	1.51	95.5	922
40	R	624	472	1.33	95.1	912
40	S	796	495	1.61	95.2	879
Pooled SEM		18.6	16.7	0.05	1.1	45.2
Means of main effects[d]						
28		711	492	1.44	96.7	884
32		731	485	1.50	97.6	826
36		724	495	1.47	96.1	868
40		710	484	1.47	95.1	896
	R	627y	461 y	1.37 y	96.2	820y
	S	810 x	517 x	1.57 x	96.6	916x
ANOVA (*P* values)						
Dietary protein (DP)		0.61	0.90	0.65	0.13	0.45
Feeding rate (FR)		<0.001	<0.001	<0.001	0.62	<0.005
DP x FR		0.75	0.38	0.27	0.20	0.14

[a]*R = restricted (≤ 90 kg/ha per d); S = satiation.*
[b]*Mean initial weight of fish was 63.8 g/fish.*
[c]*Individual treatment means represent average values of five ponds. The Fisher's protected LSD procedure was not conducted for individual means because there was no interaction.*
[d]*Means of main effects within a column followed by different letters were different (P ≤ 0.05, LSD procedure).*

Results

Dietary protein concentration had no effect on feed consumption, weight gain, feed conversion ratio, survival, or aeration time (Table 2). The only factor that affected these variables was feeding rate. Fish fed to satiation consumed more feed, gained more weight, had a higher feed conversion ratio, and required more aeration time than fish fed at a restricted rate (Table 2). Also, there were no interactions between dietary protein concentration and feeding rate on these variables. Visceral fat decreased as dietary protein concentration increased to 36% and as feeding rate decreased (Table 3). Carcass yield increased with dietary protein increased to 32%. Fillet yield increased with dietary protein increased to 36%. There were no interactions between dietary protein concentration and feeding rate on visceral fat and processing yields. Dietary protein concentration did not affect fillet moisture, protein, or fat levels; however, fillets from fish fed to satiation contained less moisture and more fat than those fed at a restricted rate (Table 4). There were no interactions between dietary protein and feeding rate on fillet proximate composition.

For pond water TN, there were interactions among dietary protein level, feeding rate, and week, between dietary protein and feeding rate, and between feeding rate and week (Table 5). There was also an interaction between feeding rate and week for TAN. Total ammonia-nitrogen, NH_3-N, and NO_2-N concentrations were higher in ponds where fish were fed higher protein feeds.

Results in Table 6 indicated little effect of experimental treatment on pond water SRP or chlorophyll-*a* concentrations. There was an interaction

TABLE 3. *Mean processing yield of pond-raised channel catfish fed once daily to satiation or at a rate of ≤ 90 kg/ha per d with feeds containing various levels of protein.*

Dietary protein (%)	Feeding rate[a]	Visceral fat (%)	Carcass yield[b] (%)	Fillet yield (%)	Nugget (%)
Individual treatment means[c]					
28	R	3.33	65.9	35.9	9.15
28	S	3.53	66.2	36.5	9.40
32	R	3.33	66.2	36.5	9.33
32	S	3.60	67.0	37.4	9.20
36	R	2.99	66.6	37.4	9.44
36	S	3.28	67.0	37.4	9.31
40	R	3.00	67.0	37.6	9.22
40	S	3.48	67.1	37.6	9.34
Pooled SEM		0.11	0.35	0.30	0.11
Means of main effects[d]					
28		3.43 ab	66.0b	36.2 b	9.28
32		3.46 a	66.6 a	36.9b	9.27
36		3.14 c	66.8 a	37.4 a	9.38
40		3.24 bc	67.0 a	37.6 a	9.28
	R	3.17 y	66.4	36.8	9.29
	S	3.47 x	66.8	37.2	9.31
ANOVA *P* values)					
Dietary protein (DP)		0.017	0.048	<0.001	0.74
Feeding rate (FR)		<0.001	0.093	0.071	0.75
DP x FR		0.62	0.73	0.28	0.27

[a]*R = restricted (≤ 90 kg/ha per d); S = satiation.*
[b]*Carcass yield is percentage of carcass (with skin, but without head and viscera) weight relative to whole body weight.*
[c]*Individual treatment means represent average values of five ponds with 30 fish per pond.*
The Fisher's protected LSD procedure was not conducted for individual means because there was no interaction.
[d]*Means of main effects within a column followed by different letters were different ($\underline{P}$ ≤ 0.05, Fisher's protected LSD procedure).*

between dietary protein level and feeding rate for COD. Ponds in which fish were fed a 36% protein feed to satiation had higher COD than fish fed at the restricted rate with the same feed. However, this difference was not observed in ponds in which other feeds were fed. In the satiation feeding group, ponds in which fish were fed the 36% protein feed had a higher COD than ponds in which fish were fed other feeds. However, in the restricted feeding group, there were no differences in pond water COD among different treatments. An interaction between dietary protein and week on TP was also observed.

Discussion

Our data do not support the generally held premise that channel catfish fed to less than satiety require higher protein feeds. Although fish fed at a restricted rate gained less weight than those fed to satiation, increasing dietary protein to above 28% had no effect on weight gain or feed conversion of fish fed a restricted ration. This is in contrast to earlier studies with channel catfish (Minton 1978; Li and Lovell 1992c), but is in agreement with a recent study (Robinson and Li 1999a). Differences in experimental design and conditions could have contributed to contrasting results among these studies; however, differences in feeding rate appear to be the primary factor. Specifically, feed was restricted to 60 kg/ha per d in the study of Li and Lovell (1992c); whereas, in the present study, feed was restricted to 90 kg/ha per d. The rate used in the present study was similar to that used on commercial catfish farms. Many catfish

TABLE 4. Mean moisture, protein, and fat concentrations (wet tissue basis) of fillets of pond-raised channel catfish fed once daily to satiation or at a rate of ≤ 90 kg/ha per d with feeds containing various levels of protein.

Dietary protein (%)	Feeding rate[a]	Fillet moisture (%)	Fillet protein (%)	Fillet fat (%)
Individual treatment means[b]				
28	R	75.6	17.1	6.26
28	S	76.2	16.5	6.38
32	R	76.5	17.1	5.43
32	S	75.1	16.8	7.11
36	R	77.0	16.6	5.43
36	S	75.5	17.2	6.47
40	R	76.1	17.6	5.46
40	S	75.6	17.2	6.40
Pooled SEM		0.46	0.28	0.35
Means of main effects[c]				
28		75.9	16.8	6.32
32		75.8	17.0	6.27
36		76.2	16.9	5.95
40		75.9	17.4	5.93
	R	76.3 x	17.1	5.65 y
	S	75.6y	16.9	6.59x
ANOVA (*P* values)				
Dietary protein (DP)		0.75	0.19	0.56
Feeding rate (FR)		0.035	0.32	<0.001
DP x FR		0.11	0.17	0.19

[a]*R = restricted (≤ 9 kg/ha per d); S = satiation.*

[b]*Individual treatment means represent average values of five ponds with 10 fish per pond.*

The Fisher's protected LSD procedure was not conducted for individual means because there was no interaction.

[c]*Means of main effects within a column followed by different letters were different (P ≤ 0.05, Fisher's protected LSD procedure).*

farmers feed to apparent satiety; however, if feed is restricted a typical cutoff level approximates 112 kg/ha per d.

Another issue regarding dietary protein concentration is the increased body fat content of fish fed low protein feeds. For example, if dietary protein is reduced to too low a level, the dietary DE:P ratio increases to a point that generally results in fatter fish (Li and Lovell 1992a; Robinson and Li 1997; Li et al. 2000). Although moderate increases in body fat content are generally acceptable, a significant increase could negatively affect processing yield. Reducing dietary protein from 32% to 28% typically increases body fat only slightly, without affecting processing yield (Li et al. 2000). In the present study, levels of dietary protein had no effect on fillet proximate composition and only minimal effect on visceral fat and carcass yield. Carcass yield was lower for fish fed the 28% protein feed; however, percentage visceral fat was similar. Because increased visceral fat is usually equated to reduced carcass yield, the difference in carcass yield was probably due to other unknown factors. Although we cannot say for certain what caused this response, it is known that it usually takes a more drastic reduction in dietary protein than was used in this study to significantly affect body fattiness and processing yield. Body fat content increases substantially; whereas, carcass and fillet yield are typically reduced in fish fed feeds containing 24% or less protein. This effect is more pronounced as dietary protein is reduced to even lower levels (Robinson and Li 1997, 1998; Li et al. 2000).

TABLE 5. *Means and ranges (in parenthesis) of nitrogenous waste compounds in pond water where channel catfish were fed once daily to satiation or at a rate of ≤ 90 kg/ha per d with feeds containing various levels of protein.*

Daily Protein (%)	Feeding rate[a]	Total nitrogen[b] (mg/L)	Total ammonia-nitrogen[b] (mg/L)	Un-ionized ammonia-nitrogen[c] (mg/L)	Nitrite-nitrogen[b] (mg/L)
Individual treatment means[d] and ranges[e]					
28	R	3.1 (0.9-7.8)	1.01 (0-2.4)	0.142 (0.0.55)	0.013 (0-0.18)
28	S	3.6 (1.2-6.5)	1.13 (0-2.7)	0.155 (0-0.80)	0.025 (0-0.29)
32	R	3.0 (0.9-5.8)	1.07 (0-2.6)	0.150 (0-0.53)	0.010 (0-0.19)
32	S	3.8 (1.5-8.9)	1.20 (0-3.0)	0.161 (0-0.55)	0.032 (0-0.32)
36	R	2.9 (0.7-7.5)	1.18 (0.2-2.6)	0.164 (0.02-0.80)	0.033 (0-0.30)
36	S	5.0 (1.1-11.5)	1.23 (0-3.4)	0.181 (0-0.75)	0.044 (0-0.40)
40	R	4.1 (1.4-7.3)	1.24 (0.3-2.8)	0.190 (0.03-1.4)	0.048 (0-0.25)
40	S	4.1 (1.2-8.1)	1.29 (0.1-2.7)	0.186 (0.03-0.69)	0.035 (0-0.30)
Pooled SEM		0.33	0.05	0.008	0.008
Means of main effects[f]					
28		3.4	1.07 c	0.149 c	0.019 b
32		3.4	1.14 bc	0.155 c	0.021 b
36		4.0	1.20 ab	0.172 b	0.038 a
40		4.1	1.26 a	0.188 a	0.042 a
	R	3.3	1.12	0.162	0.026
	S	4.2	1.21	0.170	0.034
ANOVA (*P* values)					
Dietary protein (DP)		0.061	0.006	<0.001	0.01
Feeding rate (FR)		<0.001	0.025	0.13	0.16
DP x FR		0.022	0.83	0.58	0.17
Week (W)		<0.01	<0.001	<0.001	<0.001
DP x W		0.056	0.32	0.07	0.39
FR x W		0.040	0.008	0.15	0.07
DP x FR x W		<0.001	0.98	0.83	0.59

[a] *R + restricted (≤ 90 kg/ha per d); S = satiation.*
[b] *Samples were taken and measured once weekly at approximately 1300 to 1600 h from May to September.*
[c] *Un-ionized ammonia-nitrogen was calculated based on total ammonia-nitrogen and maximum water temperature and pH (Tucker and Robinson 1990).*
[d] *The Fisher's protected LSD procedure was not conducted for individual means because there was no interaction between stocking density and dietary protein.*
[e] *Ranges represent minimujm and maximum concentrations among all measurements within the same treatment.*
[f] *Means of main effects within a column followed by different letters were different (P ≤ 0.05, Fisher's protected LSD procedure).*

The authors have conducted several studies on protein nutrition of channel catfish and have observed variable results with regard to body fat content and processing yield (Robinson and Li 1999b). Some of these differences were likely related to variance in fish populations. However, in general, the results indicate that decreasing dietary protein in channel catfish feeds to some critical level (about 24%) results in a major imbalance between dietary protein and energy leading to increased fattiness and a possible reduction in processing yield. Thus, increasing dietary protein could reduce fattiness and increase processing yield. As dietary protein is increased, dietary DE: P ratio becomes more optimized. Data from the present study show that dietary protein must be increased to at least 36% to significantly increase fillet yield over fish fed a 28% or 32% protein feed. These data are supported by the earlier work of Li et al. (2000).

TABLE 6. *Means and ranges (in parenthesis) of chemical oxygen demand (COD), total phosphorus, soluble reactive phosphorus (SRP), and chlorophyll-a in pond water where channel catfish were fed once daily to satiation or at a rate of ≤ 90 kg/ha per d with feeds containing various levels of protein.*

Daily Protein (%)	Feeding rate[a]	COD[b] (mg/L)	Total phosphorus[b] (mg/L-P)	SRP[b] (mg/L-P)	Chlorophyl-a[b] (mg/L)
Individual treatment[c] and ranges[d]					
28	R	27.7 (3.4-58.8)bc	0.38 (0.20-0.79)	0.13 (0.02-0.38)	84.5 (14.1-188.4)
28	S	34.0 (1.1-92.0) bc	0.43 (0.26-0.89)	0.16 (0.02-0.41)	107.2 (28.8-279.0)
32	R	31.4 (3.8-97.2)bc	0.40 (0.21-0.61)	0.11 (0.03-0.37)	101.7 (19.9-293.3)
32	S	32.4 (5.4-923.9)bc	0.42 (0.26-0.66)	0.17 (0.04-0.60)	93.1 (24.6-227.9)
36	R	26.8 (8.0-67.8)c	0.36 (0.11-0.97)	0.14 (0.02-0.40)	102.2 (9.9-347.5)
36	S	41.4 (14.1-99.8)a	0.45 (0.12-0.86)	0.14 (0.01-0.44)	101.9 (2.6-265.9)
40	R	29.6 (7.1-70.4)bc	0.42 (0.25-0.69)	0.16 (0.02-0.69)	102.3 (21.5-362.0)
40	S	34.4 (9.8-84.2)b	0.42 (0.21-0.77)	0.14 (0.01-0.44)	111.3 (11.1-274.2)
Pooled SEM		2.4	0.03	0.02	7.5
Means of effects[e]					
28		30.8	0.40	0.14	95.9
32		31.9	0.41	0.14	97.4
36		34.1	0.41	0.14	102.0
40		32.0	0.42	0.15	106.8
	R	28.9	0.39	0.14	97.7
	S	35.6	0.43	0.15	103.4
ANOVA (*P* values)					
Dietary protein (DP)		0.57	0.95	0.94	0.47
Feeding rate (FR)		<0.001	<0.001	<0.001	<0.001
DP x FR		0.050	0.48	0.13	0.21
Week (W)		<0.001	<0.001	<0.001	<0.001
DP x W		0.14	0.036	0.77	0.78
FR x W		0.11	0.20	0.51	0.88
DP x FR x W		0.67	0.29	0.79	0.63

[a]*R = restricted (≤ 90 kg/ha per d); S = satiation.*
[b]*Samples were taken and measured once biweekly at approximately 1300 to 1600 h from May to September.*
[c]*The Fisher's protected LSD procedure was not conducted for individual means because there was no interaction between stocking density and dietary protein.*
[d]*Ranges represent minimujm and maximum concentrations among all measurements within the same treatment.*
[e]*Means of main effects within a column followed by different letters were different (P ≤ 0.05, Fisher's protected LSD procedure). Pooled means for COD were reported but not statistically compared because there was a significant interaction between dietary protein and feeding rate.*

An overall observation from the present study was that feeding to satiety resulted in an increase in visceral and fillet fat, but had no significant effect on processing yield. In general, fattiness increases in channel catfish fed a full ration. This can be explained by increased energy consumption and subsequent fat deposition. However, an increase in fattiness, regardless of the causative factor, does not always result in a decrease in processing yield.

Ultimately, catfish producers can increase profitability by feeding low protein feeds; however, losses in revenue due to reduced processing yield could occur if dietary protein is reduced to below the minimal level. This situation presents a dilemma—the producer is not generally paid on the basis of processing yield, and thus has little incentive to feed a more expensive feed to increase processing yield, particularly when fish prices are low. On the other hand, the processor may penalize producers whose fish do not provide the yield they desire, in effect resulting in the producer being paid based on processing yield. Because of all the complicating factors involved in establishing fair pricing policy based on processing yield, it appears that the best solution is to use a 28% protein feed that would result in considerable savings to the producer and have little, if any, impact on processing yields.

Because the amount of nutrients that can be effectively metabolized by an aquaculture pond is limited (Boyd and Tucker 1998), reducing nutrient input into the pond might improve water quality. There were statistical differences and interactions among the water quality factors, but their biological significance was difficult to determine because they did not appear to affect fish production. Examining treatment means pooled over all treatments, nitrogenous waste compounds TN, TAN, NH_3-N, and NO_2-N were generally higher in ponds receiving the higher protein feeds. These results generally agreed with data reported by Li and Lovell (1992b). However, there were no effects of feeding rate on pond water nitrogenous waste compounds. There were also no differences in pond water chlorophyll-a concentrations among treatments. In contrast, Cole and Boyd (1986) reported that pond water nitrogenous waste compounds and chlorophyll-*a* increased as feeding rates increased. The different results from the present study and that of Cole and Boyd (1986) in nitrogenous waste compounds and chlorophyll-a could have been due to the relatively smaller differences in feeding rates used in the present study, in which fish in the satiation group were fed about 30% more feed than fish fed the restricted ration, whereas feeding rate used in the study of Cole and Boyd (1986) varied from 0 to 224 kg/ha per d.

Although there was a significant interaction in pond water COD between dietary protein and feeding rate, generally ponds in the satiation feeding group had higher COD than ponds in the restricted feeding group. Cole and Boyd (1986) also reported that as feeding rate increased COD increased. There was a trend that pond water TP levels were slightly elevated in the satiation feeding group compared to the restricted feeding group ($P = 0.071$). However, pond water SRP was not different among treatments. The lack of a strong relationship between dietary phosphorus input and pond water SRP and chlorophyll-a concentrations in the present study appeared to agree with results of Gross et al. (1998), who reported that dietary phosphorus levels did not strongly influence pond water phosphorus and chlorophyll-a levels.

Aeration time increased by about 12% in ponds in which fish were fed to satiety compared to those fed a restricted ration. This appears to be an expected response to an increase in organic loads in ponds receiving the full ration. There may be a small savings on electricity use by reduced aeration time and equipment depreciation for ponds in which fish are fed a restricted ration.

Conclusion

Based on the data presented herein, we conclude that channel catfish fed a 28% protein feed can achieve the same level of production as those fed a 40% protein feed, even when feeding rate is restricted to 90 kg/ha per d. However, fillet yield could be improved by increasing dietary protein to 36% or above. We suggest that with fish prices declining, it would be unwise to pay for the high protein feed unless a premium is paid for higher yielding fish. Further, although there was an increase in nitrogenous wastes in ponds where fish were fed high protein feeds, there was little effect on fish production. The long term effects of using high protein feeds on water quality in a situation where the ponds might not be drained for several years is presently unknown. It also appears that reducing organic loads in pond water could reduce aeration costs; perhaps even more important could be the unmeasured effects of reducing organic loads on fish health. Lastly, it appears that feeding to less than satiety may be beneficial in improving feed efficiency and water quality.

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